# Geophysical Fluid Flow Cell Experiment

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The Geophysical Fluid Flow Cell (GFFC) experiment simulates a wide variety of thermal convection phenomena in spherical geometry. By applying an electric field across a spherical capacitor filled with a dielectric liquid, a body force analogous to gravity is generated around the fluid. The force acts as a buoyant force in that its magnitude is proportional to the local temperature of the fluid and in the radial direction perpendicular to the spherical surface. In this manner, cooler fluid sinks toward the surface of the inner sphere while warmer fluid rises toward the outer sphere. The value of this artificial gravity is proportional to the square of the voltage applied across the sphere and can thus be imposed as desired. With practical voltages, its magnitude is only a fraction of Earth's and so requires a microgravity environment to be significant.

The GFFC flew aboard the second United States Microgravity Laboratory (USML–2) October 20 to November 5, 1995 on *Columbia*. The instrument carried out 29 separate 6-hr runs using different parameters (cell rotation rate, heating distributions, etc.). Eighteen of the runs were nominal in terms of instrument performance, except for indications that suggested higher-than-expected temperatures along the outer sphere's equator. Because of this overtemperature problem, science activities were focused on situations with spherically symmetric heating (the so-called "solar model" cases). The last 11 runs were affected by a problem with the 16-mm film transport, leaving the video as the primary data source. This was compensated for by running experiments towards the end of the mission with commanded boundary temperatures similar to those run earlier in the mission on which film data is available.

The following are the preliminary results based on video downlink recorded during the USML–2 mission (analysis of the 16-mm film data has recently commenced at the University of Colorado). The experiments fell into several classes depending on the rotation rate (rapid or slow: e.g., solar-like or mantle-like). In each case new states were observed and are summarized here.

Studies of rotating convection with spherically symmetric heating revealed possible multiple jets in latitude, with prograde (same sense as the basic rotation) motion of thermal waves at low and high latitudes and retrograde pattern rotation at mid-latitude. Such differential pattern propagation has not been previously seen in computational models, and these results may provide an alternative view on the mechanisms for "banded"-looking structures in planetary atmospheres like Jupiter. However, contrary to suggestions from our Taylor-column idealized models, no vacillatory (periodic global pulsation) states were observed.

An extensive study of slowly rotating convection was carried out, and two distinct convection patterns were observed in experiments with the same external parameters but with different initial conditions. This means that the long-time evolution of modestly convecting flows in slowly rotating spherical shells (like Earth's mantle) is not unique, but depends on initial conditions. Equivalently the "climate" can be persistent, or locked, for long times as external conditions change slowly. In addition, information was obtained on how these persistent states evolve as parameters are increased across stability boundaries. Experiments produced an instability of "horseshoe convection," wherein the off-center ring of convection breaks down by north-south oriented stripe formation as the voltage is increased from 1.44 kV to 1.56 kV.

A large data set (several different rotation rates, many different heating rates) was obtained on the transition between anisotropic north-south oriented "banana convection" and more isotropic nonaligned convection. These results, when quantified by digital analysis of the data films and tapes, will permit testing of simple scaling arguments for this transition. Once verified, these scalings can be used to classify the expected global convection regimes of planets and stars.

Experiments with latitudinal heating gradients showed evidence for baroclinic waves. This instability is interesting because it has combined attributes of both ordinary thermal convection and rotating slantwise convection. The latter instability is central to the circulation of the Earth's atmosphere, but its occurrence as a combined instability supports recent computational modeling of such instabilities in rotating spherical shells.

Other experiments with latitudinal heating showed how spiral wave convection breaks down to turbulence by secondary branching.

[1]Hart, J.E.; Glatzmaier, G.A.; Toomre, J.: "Space-Laboratory and Numerical Simulations of Thermal Convection in a Rotating Hemispherical Shell With Radial Gravity." *Journal of Fluid Mechanics*, vol. 173, pp. 519–544, 1986.

[2]Brummell, N.; Hart, J.E.: "High Rayleigh Number Beta-Convection." Geophysical and Astrophysical Fluid Dynamics, pp. 85–114, 1993.

[3]Sun, Z.-P; Shubert, G.; Glatzmaier, G.A.: "Banded Surface Flow Maintained By Convection in a Model of the Rapidly Rotating Giant Planets." *Science*, vol. 260, pp. 661–664, 1993.

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**Biographical Sketch:** Fred Leslie is a scientist in the Microgravity Science and Application Division at MSFC. He served as a payload specialist astronaut aboard the Space Shuttle *Columbia* on the USML–2 (STS–73) mission in October/November 1995. He operated a number of experiments during the 16-day mission including the GFFC investigation.